The DANCe project or how to recycle 15 years of archival wide-field data for kinematic studies

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Abstract

The DANCE (Dynamical Analysis of Nearby ClustErs) project aims at deriving a comprehensive census of the stellar and substellar content of a number of nearby (<1 kpc) young (<500 Myr) associations. Members are identified based on their kinematics properties, ensuring little contamination from background and foreground sources. We show how robust individual proper motions can be computed with a precision better than 1 mas/yr by combining thousands of wide-field images downloaded from public archives and covering more than a decade of observations.

1 Introduction

The *GAIA* mission (Perryman et al., 2001) will provide a stereoscopic and kinematic census of about one billion stars with unprecedented accuracy down to V≈20 mag. *GAIA* will unfortunately not be sensitive enough to low mass objects: at 100 pc, an apparent magnitude of V≈20 mag corresponds to ≈25 M_{Jup} for an age of 1 Myr (Baraffe et al., 1998), while the mass function is known to extend at least down to 3∼4 M_{Jup}. In addition, because it will operate in the visible, *GAIA* will be even less sensitive in regions of heavy extinction and bright nebular emission, where precisely most of the star formation is taking place. Taking advantages of a decade and a half of wide field observations with digital detectors, we have embarked in a comprehensive study of kinematics in a number of nearby (≤ 1 kpc) associations and clusters: the DANCE project. Complementing archival data with deep wide field observations, we are compiling a multi-epoch panchromatic database encompassing large areas (several tens of square degrees each) around young nearby associations. From this database we derive accurate transverse motions for all sources with detections at multiple epochs. Our main scientific goal is to derive accurate stellar mass functions based on proper-motion-selected cluster members, and to study the kinematic distribution of confirmed members. However our proper motion database can also be used for completely different studies such as galactic dynamics or small-body discovery/recovery.

In section §2 we describe briefly the main steps of our fully automated astrometric pipeline.

Some results obtained on a first ≈ 80 square-degree field centred on the Pleiades are presented in §3. Finally in section §4 we show how a similar automated analysis could easily be extended to photographic plates, potentially covering a much larger time base.

2 Method

One of the main challenges for the pipeline is to provide robust, fully automated operations for a wide variety of imaging data, with very heterogeneous quality. For instance, in the Pleiades study, more than 16,000 exposures coming from nine different instruments were downloaded from archives and processed (Fig. 1), with seeing Full-Widths at Half-Maximum ranging from 0.4 to 2.5", and exposure times between a few seconds and thirty minutes. 2.6% of the exposures were rejected by our semi-automated quality control procedure. Another difficulty with archival data is inconsistent or even missing metadata, especially with early instruments.

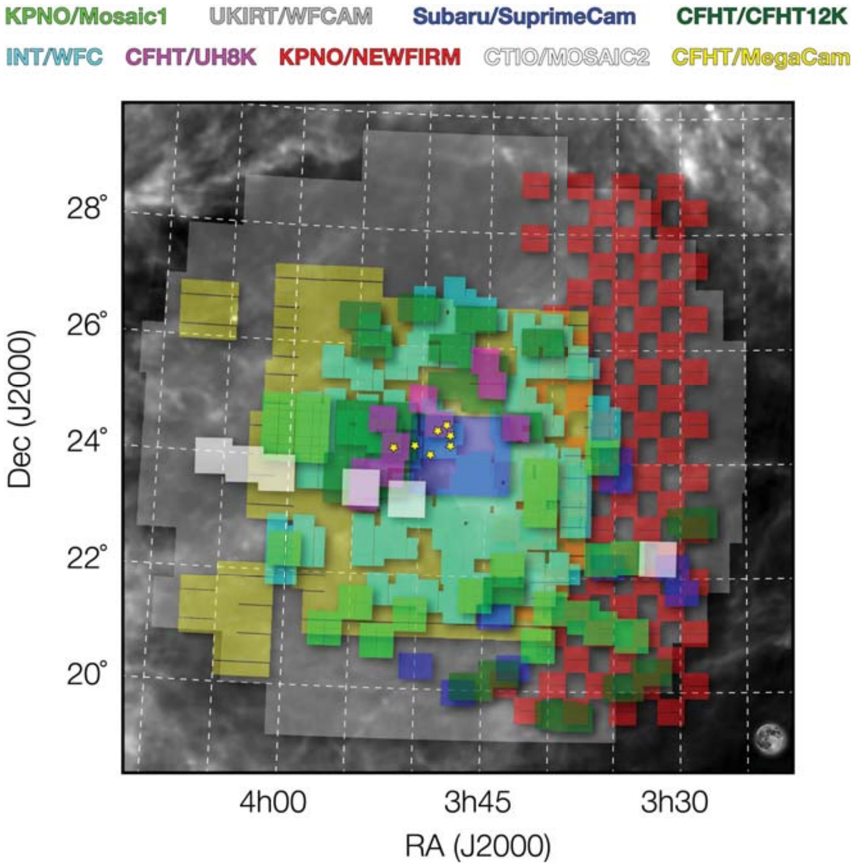

Figure 1: Coverage of the Pleiades field by the various instruments used for the DANCe project, with the IRAS map at 100μm in the background. The footprint of the full Moon is shown in the lower right corner for comparison.

Figure 2 illustrates the main steps of our astrometric pipeline; more details can be found in Bouy et al. (2012). Briefly, detrended exposures are separated in groups that share the same instrument, the same photometric band and the same observing run. We extract all sources above a given detection threshold (Bertin & Arnouts, 1996), and measure fluxes and positions through PSF-convolved Sérsic (1968) model fitting (Bertin, 2011), which works equally well for point sources and galaxies. All the extracted catalogues are then processed by the SCAMP software (Bertin, 2006) to compute a global astrometric solution by minimizing the weighted,

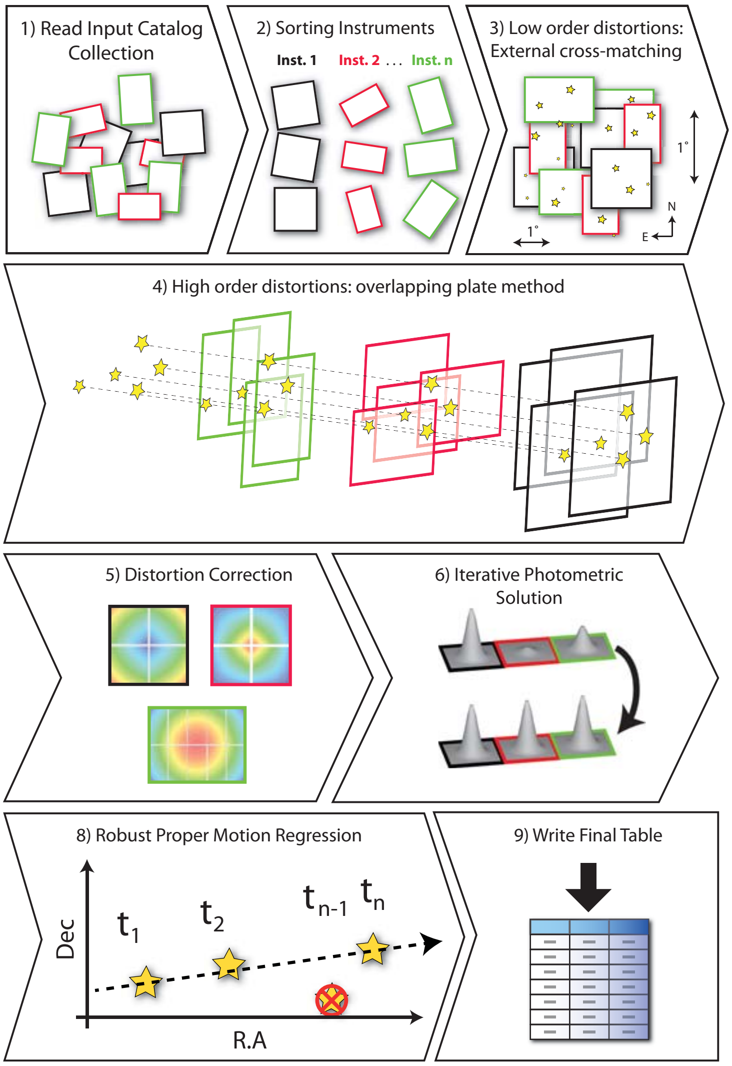

Figure 2: Graphical illustration of the various steps of the astrometric pipeline.

quadratic sum of mutual differences between the positions of all overlapping detections (e.g., Eichhorn, 1960; Kaiser et al., 1999), anchored to the 2MASS catalogue (Skrutskie et al., 2006). SCAMP clips detections with large positional deviations between two successive iterations of the solution to minimise the impact of source mismatches and large transverse motions. The last step performed in SCAMP is the computation of individual proper motions from multiple epochs, using a matching procedure optimised for moving object, and a linear χ^2 minimisation scheme with iterative rejection of outliers. Note that contrary to the traditional approach with small astrometric surveys, SCAMP computes proper motions directly from the coordinates coming out of the solution, and not from coordinates relative to neighbours.

The distribution of proper motions coming out of SCAMP can be offset by a few mas/yr with respect to the GCRS, largely because of the influence exerted by the Galactic disk's relative bulk motion on the solution. We correct for this effect by letting the population of sources identified as extended (essentially galaxies) set the zero of proper motions. Statistical arguments as well as checks with known quasars and other catalogues indicate that residual systematics with respect to the GCRS are typically 0.2-0.3 mas/yr in the Pleiades sample.

3 Results

The final DANCe catalogues contain accurate positions, proper motions, fluxes, colour indices, morphometric information as well as the associated uncertainties for all individual sources. Figure 3 shows examples of proper motion diagrams obtained in the Pleiades field down to $i \approx 24$ mag. An interesting by-product of this study is the discovery/recovery of thousands of solar system bodies, captured throughout "dithered" sequences of wide-field exposures. As of August 2012, less than a quarter of them have a counterpart within 1 arcmin in the SkyBoT (Berthier et al., 2006) database of known solar system bodies (all of them main belt asteroids). Figure 4 shows an example of a faint moving object found by our pipeline, most probably a main belt asteroid.

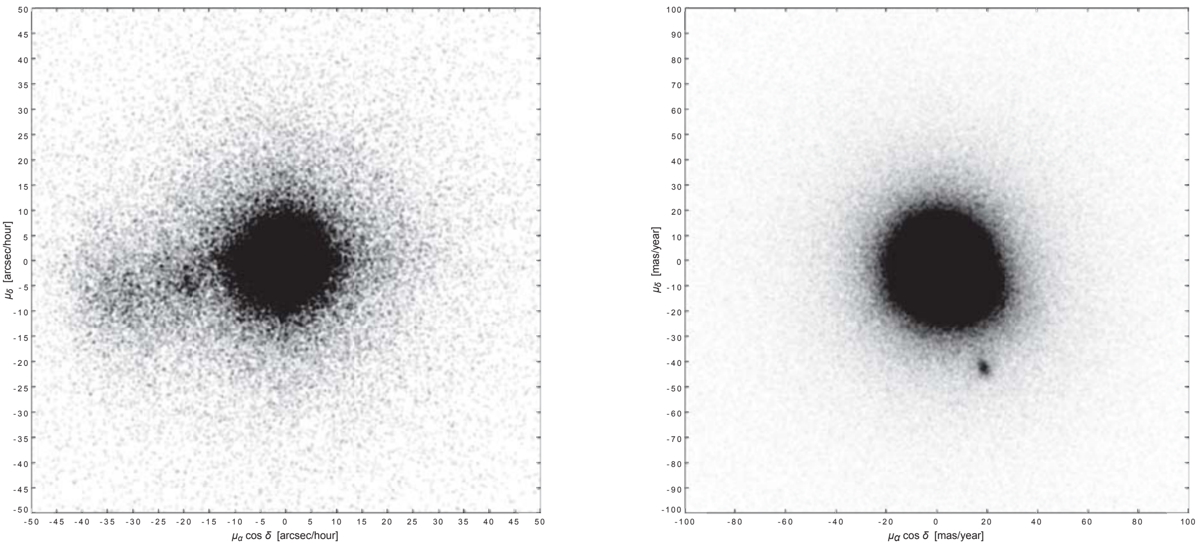

Figure 3: Proper motion diagram for the Pleiades field ($\approx$ 6 million sources) plotted at two different scales.(*Left:* $\pm$50 arcsec/hour, showing a concentration of asteroid motions aligned roughly with the ecliptic (to the left of the central clump of background sources). *Right:* $\pm$100 mas/yr (zoomed $\approx$ 9 millions times!), showing the locus of the Pleiades members as a small spot well isolated from the central clump of background sources (slightly asymmetrical because of our motion towards the solar apex).

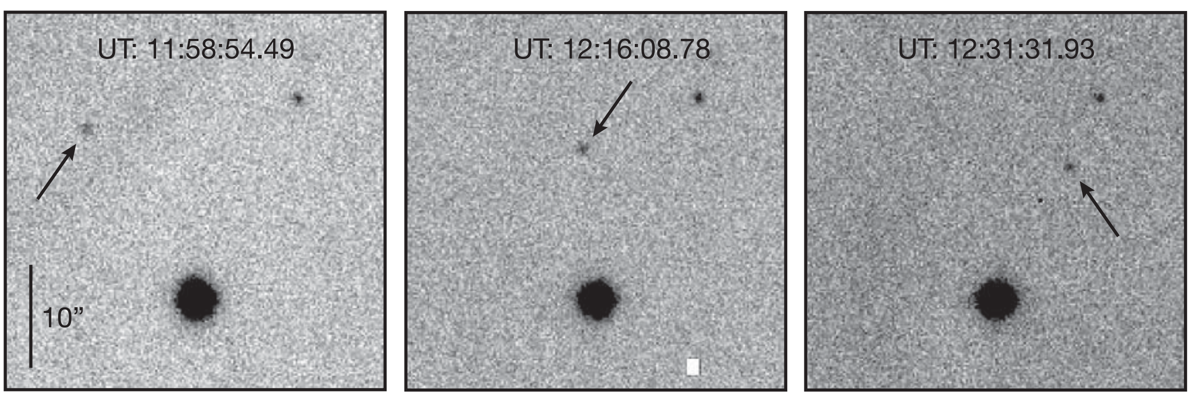

Figure 4: Successive CFHT Megacam images of a moving object with magnitude g= 23.1, most probably a main belt asteroid. Three out of the nineteen exposures are shown here.

4 Working with photographic plates

SCAMP is used routinely to calibrate individual photographic plates (e.g., Servillat et al., 2011). But it is also possible to apply the full DANCe treatment to overlapping plates obtained at different epochs (together with modern digital data or not) to derive accurate positions and proper motions. Figure 5 shows a practical example with a set of scans from eight partially overlapping survey Schmidt plates taken near the south celestial pole between 1976 and 1990, and part of the VO Paris Southern Atlas (Le Sidaner et al., 2008). Despite the small number of epochs (between two and seven), and a relatively short average timebase of 5 years, the agreement with UCAC-4 proper motions (Zacharias et al., this conference) is excellent.

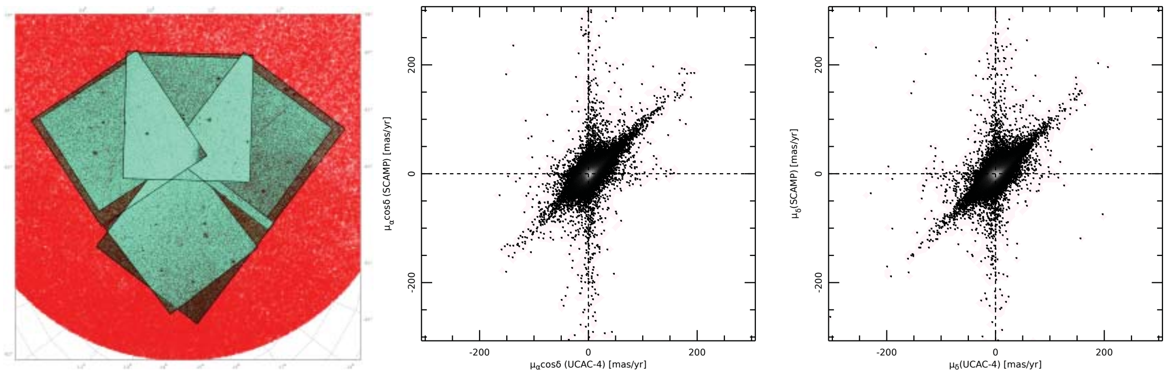

Figure 5: The DANCe pipeline applied to a set of overlapping Schmidt survey plates. *Left:* distribution of detections matched between plates (cyan) and unmatched UCAC-4 stars (red).*Middle and Right:* proper motions along Right Ascension and Declination derived by SCAMP from the Schmidt plate data (ordinate) versus proper motions in the UCAC-4 catalogue (abcissa).

5 Conclusion

The DANCe project illustrates the possibility to use heterogeneous combinations of archival wide-field camera data to extend GAIA astrometry and proper motion measurements to significantly fainter (and/or redder) magnitudes in regions of strong scientific interest. Moreover, as we have shown, overlapping sets of legacy photographic plates can also be processed with the same fully automated pipeline, which could be a valuable tool for studies requiring a wider (or different) time base with respect to GAIA.

The SExtractor, PSFEx and SCAMP and WeightWatcher software packages used in this study are freely available from the `astromatic.net` website.

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